EVALUATION OF THE EFFECTS OF CRUMB RUBBER AND SBR ON RUTTING RESISTANCE OF ASPHALT CONCRETE

Chuang-Tsair Shih, Mang Tia & Byron E. Ruth
Department of Civil Engineering
University of Florida
Gainesville, FL 32611

Keywords: Crumb rubber, SBR, rutting resistance.

ABSTRACT

This paper presents the results of a study to evaluate the effects of addition of crumb rubber (CR) and styrene-butadiene rubber (SBR) on the rutting resistance of asphalt concrete. These two additives were blended with an AC-20 and an AC-30 grade asphalt cements at different levels of concentrations. These modified and unmodified asphalt blends were tested at intermediate and high temperatures to evaluate their rutting resistance characteristics. They were also used to make Florida type S-I structural surface mixtures. These mixtures were made into Marshall-size specimens by using Gyratory Testing Machine (GTM) equipped with air-roller to compact and densify to three compaction levels which simulate three different conditions in the pavement. The FDOT's (Florida Department of Transportation) Loaded Wheel Tester was also used to evaluate the rutting resistance of these asphalt mixtures. The test results indicate that the modified asphalt mixtures show relatively better rutting resistance and shear resistance as compared with the unmodified asphalt mixtures.

INTRODUCTION

With the increasing load and pressure of vehicles tires which are applied to our highway pavements today, one of the major distresses seen on our highway pavements is rutting. One of the promising options to lessen this problem is the use of polymers to modify the asphalt binders. The addition of polymers usually has the effect of increasing the stiffness of the binders at high service temperatures without increasing the stiffness at low service temperatures. This modification of binder properties means that the asphalt mixture could be more rut resistant at high service temperatures while its cracking resistance at low temperatures would not be lessened. Crumb rubber (CR) and styrene-butadiene rubber (SBR) are two of the commonly used asphalt additives for this purpose. The purpose of this study was to conduct a laboratory evaluation of the effects of the addition of crumb rubber and SBR on the rutting resistance of typical asphalt paving mixtures used in Florida.

MATERIALS AND TESTING PROGRAM

Binders Used

Two asphalts, namely an AC-20 and an AC-30 grade asphalts, which are commonly used in Florida, were used as the reference asphalt cements. The additives used were (1) a crumb rubber with a nominal size of #80 mesh (0.177 mm), which has been used in several paving projects in Florida, and (2) a SBR, which was a copolymer of styrene and butadiene. The crumb rubber was blended with the asphalt cements in the laboratory at a temperature of 190 °C. The blending of SBR with the asphalt was done by the company that supplied these modifiers. The asphalts and modified asphalts which were used in this testing program include the following:

(1) AC-20
(2) AC-20 + 15% CR
(3) AC-20 + 3% SBR
(4) AC-30
(5) AC-30 + 10% CR
(6) AC-30 + 3% SBR

Table 1 displays the medium- and high-temperature properties of these six binders. These properties include the (1) penetration at 25°C (ASTM D5) [ASTM, 1995], (2) Brookfield viscosity at 60°C (ASTM D4402) and (3) $G^*/\sin\delta$ values as determined by the dynamic shear rheometer test (AASHTO Designation TP5) [AASHTO, 1993] at 60°C of these six binders at their original state and after the standard Thin Film Oven Test process (ASTM D1754), which simulates the short-term aging effect that occurs in the hot-mixing process.

It can be seen that at 60 °C, which represents a typical high pavement service temperature, both the CR-modified and SBR-modified asphalts are substantially stiffer than their corresponding base asphalts. However, at 25 °C, the CR-modified asphalts are only slightly harder than the base asphalts, while the SBR-modified asphalts are softer than the base asphalts, as seen from the penetration values.

Preparation of Asphalt Mixtures

Each of these six binders was mixed with a limestone aggregate blend at a binder content of 6.5% to produce mixtures which meet the requirements for a Florida DOT S-1 structural mix. Table 2 shows the specific gravities and the gradation of the aggregate blend used, along with the gradation limits for a FDOT S-1 mix.

Compaction and Testing of Asphalt Mixtures in the GTM

The Gyratory Testing Machine (GTM) (ASTM D3387) was used to compact and test these different types of asphalt mixtures. The GTM settings selected were based on the results of a previous study on simulation of traffic compaction [Ruth et al, 1994]. Nine Marshall-size specimens for each of these six different asphalt mixtures were tested. Three of the specimens were compacted to a level that simulates the initial field condition. This was achieved by applying 18 GTM revolutions at 135-149 °C (275-300 °F) using a gyratory angle of 3 degrees, 690 kPa (100 psi) of ram pressure and 62 kPa (9 psi) of air roller pressure. Another three specimens were compacted to a level that simulates the condition after two to three years of traffic. This was achieved by applying an additional 50 GTM revolutions at 60 °C at the same settings after the initial compaction. Three other specimens were compacted to a level that simulates the ultimate condition in the pavement. This was achieved by applying an additional 300 GTM revolutions at 60 °C after the initial compaction.

The gyratory shear, which is an indicator of the shear strength of the materials tested, was also measured during the GTM compaction process.

Preparation of Asphalt Mixture Specimens for Loaded Wheel Tests

The asphalt mixtures were heated to 149 °C (300 °F), mixed and then returned to the oven prior to compaction to 7.6 cm (width) X 3.8 cm (thickness) X 38.1 cm (3" X 1.5" X 15") beam specimens for the FDOT Loaded Wheel Tests. Compaction was achieved by applying a load of 60,000 lbs across the top of the beam and then releasing it, for four cycles. Then, the load of 60,000 lbs was applied for the fifth time, and held for six minutes. The compacted beams were demolded the next day, and allowed to cure at room temperature for seven days. Each beam was preheated in the test chamber at 40.5 °C (105 °F) for 24 hours before testing in the Loaded Wheel Tester.

Loaded Wheel Tests

The Loaded Wheel Tester was intended to simulate the repeated applications of moving wheel loads on the asphalt mixtures tested. A stiff pressurized hose mounted along the top of the beam acted as a tire to transfer the load from the wheel of the moving chassis to the beam. The hose pressure was set at 690 kPa (100 psi) and the moving chassis was loaded with 543 N (122 lb) of steel plates centered above the wheel. The test temperature was set at 40.5 °C (105 °F) and monitored with a thermometer embedded in a dummy specimen placed inside the Loaded Wheel Tester. One loading cycle consisted of a forward and return pass of the loaded chassis. Rut depth measurements were made with a dial gauge at seven different locations on the top of the beam at an interval of 5.1 cm (2 inches), each at 0, 1000, 4000, and 8000 cycles.

The average of three rut measurements at the center was used. This was found to be more consistent in comparison with the average of all seven measurements. The measurements at the ends of the beams tended to be exaggerated due to the combined effects of abrasion by the hose, slower moving loads at the ends and the change in pitch of the chassis.

RESULTS OF GTM TESTS

Tables 3 through 5 display the gyratory shear and the volumetric properties of the mixtures as measured by the GTM at the initial, medium and ultimate compaction, respectively. It can be seen that at the same compactive efforts, the CR-modified mixtures had lower air voids than the unmodified mixtures and the SBR-modified mixtures had the lowest air voids. It is speculated that the lower air voids of the modified mixtures were possibly due to a higher compaction temperature used for these mixtures. However, in spite of their lower air voids, the modified mixtures generally showed a higher gyratory shear strength than the unmodified mixtures, and the difference increased as the compactive effort increased.

RESULTS OF LOADED WHEEL TESTS

The results of the Loaded Wheel tests are displayed in Table 6. It can be seen that the SBR-modified asphalt mixtures show the highest reduction in rut depth as compared with the unmodified reference mixtures (up to 38% at 8000 cycles). The CR-modified mixtures showed a reduction in rut depth of 17 to 21% as compared with the unmodified mixtures. The standard deviations of rut measurements ranged between 0.03 and 0.05 inch. Results of a statistical Duncan's grouping indicate that the SBR-modified asphalt mixtures (AC-20+3%SBR and AC-30+3%SBR) had the least rut depths while the unmodified asphalt mixtures (AC-20 and AC-30) had the highest rut depths among all six types of asphalt mixtures tested.

SUMMARY AND CONCLUSION

The results of this laboratory study show that the addition of crumb rubber and SBR could increase the rutting resistance of asphalt paving mixtures. The CR-modified and SBR-modified asphalts had higher stiffness at 60 °C than the unmodified base asphalts. The modified asphalt mixtures had higher gyratory shear strengths than the unmodified mixtures. The modified mixtures exhibited substantially lower rut depths in the Loaded Wheel tests than the unmodified mixtures. It is also interesting to note, from the results of the GTM tests, that having a low air voids at ultimate compaction condition does not necessarily result in a mixture with lower shear strength.

REFERENCES

American Association of State Highway and Transportation Officials 1993. *AASHTO Provisional Standards*, AASHTO, Washington, D.C.

American Society for Testing and Materials 1995. *Annual Book of ASTM Standard*, ASTM, Philadelphia, Pennsylvania.

Ruth, B.E., Tia, M., Shen, X. and Wang, L.H. 1994. Improvement of Asphalt Mix Design to Prevent Rutting, Technical Report, Department of Civil Engineering, University of Florida, Gainesville, Florida.

Table 1 Medium- and high-temperature properties of the binders used

Asphalt Binder	Penetration at 25°C, 5sec, 100g, (dmm)		Brookfield Viscosity at 60°C at Shear Rate=1/s (poise)		G*/sinδ at 60°C at 10 rad/s (Pa)	
	Original	TFOT Residue	Original	TFOT Residue	Original	TFOT Residue
AC-20	72.5	42.2	2526	5936	3542	7383
AC-20+15%CR	51.7	38.8	20605	25352	13115	22672
AC-20+3.0%SBR	58.5	58.5	10709	14341	9304	11771
AC-30	55.0	35.8	3785	8251	4687	9330
AC-30+10%CR	47.3	34.3	9779	20424	11020	18493
AC-30+3%SBR	57.0	47.0	17407	16426	6593	12917

Table 2 Bulk specific gravities and gradation of the aggregate blend used

Sieve Size	Bulk Specific Gravity of Aggregates Retained	Gradation (% Passing)	FDOT S-I Specification (% Passing)
3/4"	---	100	100
½"	2.375	99	88 - 100
3/8"	2.379	90	75 - 93
No.4	2.345	63	47 - 75
No.10	2.298	47	31 - 53
No.40	2.333	35	19 - 35
No.80	2.655	13	7 - 21
No.200	2.784	4	2 - 6

Table 3 Mix Properties as Measured by the Gyratory Testing Machine at Initial Compaction

Mix Type	Gyratory Shear (psi)	Bulk Density (pcf)	Air Void (%)	VMA (%)
AC-20	61.00	137.2	5.90	16.04
AC-20+15%CR	63.23	137.5	5.30	15.83
AC-20+3%SBR	60.19	140.5	2.20	13.98
AC-30	59.37	137.4	4.93	15.90
AC-30+10%CR	63.38	137.7	5.20	15.75
AC-30+3%SBR	61.25	139.9	2.68	14.40

Table 4 Mix Properties as Measured by the Gyratory Testing Machine at Medium Compaction

Mix Type	Gyratory Shear (psi)	Bulk Density (pcf)	Air Void (%)	VMA (%)
AC-20	63.54	139.4	4.37	14.68
AC-20+15%CR	66.60	141.1	2.84	13.64
AC-20+3%SBR	66.76	142.1	1.10	13.01
AC-30	55.98	139.8	3.27	14.43
AC-30+10%CR	70.28	141.5	2.58	13.41
AC-30+3%SBR	67.41	142.4	0.94	12.87

Table 5 Mix Properties as Measured by the Gyratory Testing Machine at Ultimate Compaction

Mix Type	Gyratory Shear (psi)	Bulk Density (pcf)	Air Void (%)	VMA (%)
AC-20	61.55	141.4	3.02	13.47
AC-20+15%CR	66.09	142.0	2.17	13.05
AC-20+3%SBR	52.33	143.0	0.47	12.45
AC-30	61.93	141.1	3.99	14.62
AC-30+10%CR	63.41	142.4	1.93	12.84
AC-30+3%SBR	73.60	142.8	0.63	12.59

Table 6 Results of Loaded Wheel Test

	Average Rut Depth (inch)			Reduction in Rut Depth as compared with Base AC
	At 1000 Cycles	At 4000 Cycles	At 8000 Cycles	
AC-20	0.146	0.210	0.276	--
AC-20+15%CR	0.136	0.188	0.228	17%
AC-20+3%SBR	0.093	0.144	0.177	36%
AC-30	0.109	0.176	0.262	--
AC-30+10%CR	0.118	0.176	0.207	21%
AC-30+3%SBR	0.092	0.135	0.162	38%